DEVELOPMENT OF AN INTELLIGENT AGENT FOR FUTURE TACTICAL AIRCRAFT

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OUTLINE

- **PAST AND CURRENT NAVAIR PROGRAMS IN AGENT INTE**

  - **Smart Cockpit Controller (SCC) :1997-1999**
  - **Aircrew Decision Support System (ADSS) :1999 - 2001**
  - **Active Network Guidance for Emergency Logic (ANGEL)**
  - **Dynamic Task Allocation (DTA) :2001-2004**

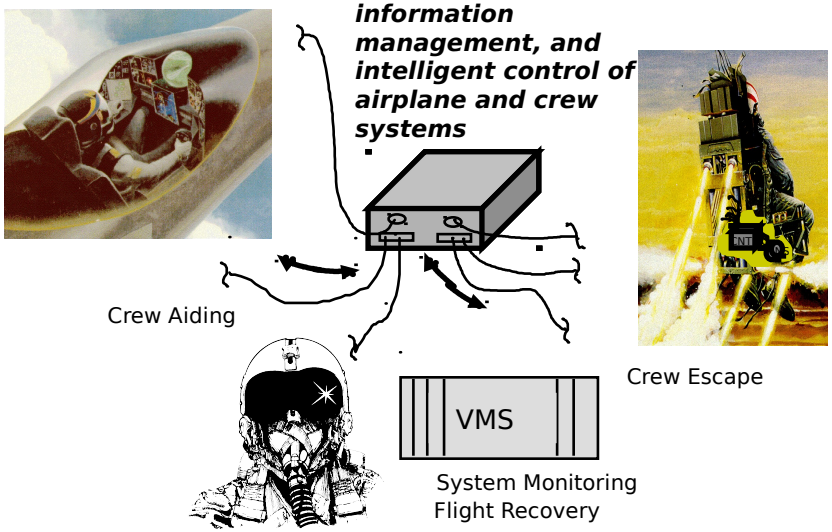
- **PROGRAM LESSONS LEARNED**

- **AGENT INTERFACE TECHNOLOGY GAPS / AREAS FOR RES**

System Concept

SMART COCKPIT CONTROLLER

AIRCREW SURVIVABILITY - AIRCRAFT SURVIVABILITY - MISSION PERFORMANCE



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SMART COCKPIT CONTROLLER
DECISION TABLE MODEL

PROBLEM AREAS

SCC ACTIONS

TRUTH TABLE KEY

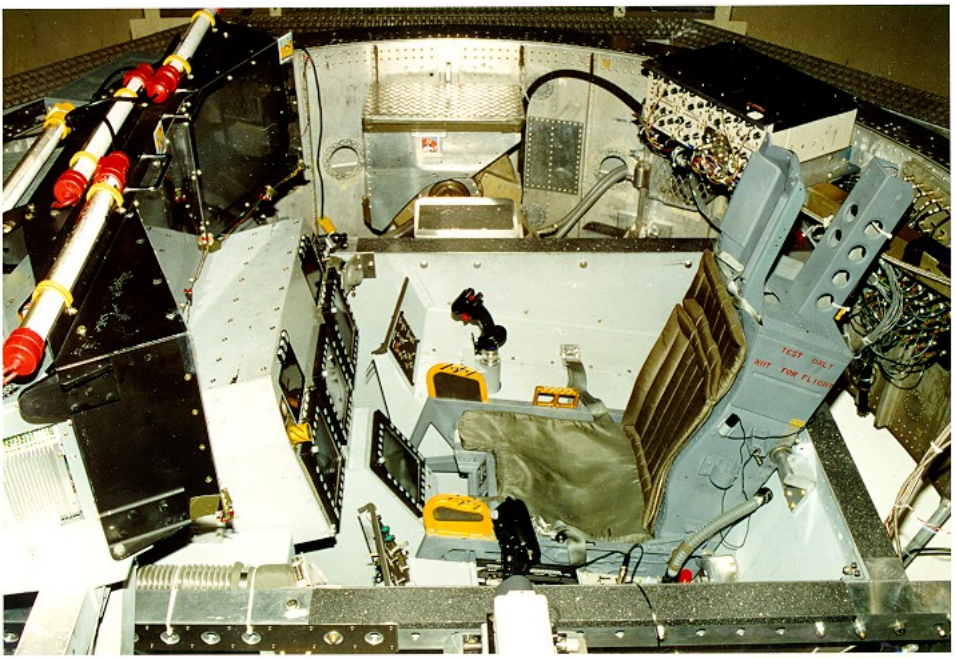
Entering Unsafe Esc Env.	1
A/C Unrecoverable	2
Pilot Disoriented	3
Pilot Work Overload	4
Pilot GLOC	5
W/in Unsafe Escape Env.	6
Imminent Threat	7
A/C Uncontrollable	8
A/C Head Below Preset Safe Altitude	9
Hydraulic Pump Failure	10
Structural Damage	11
Low Energy Mgmt State	12
Spinning	13

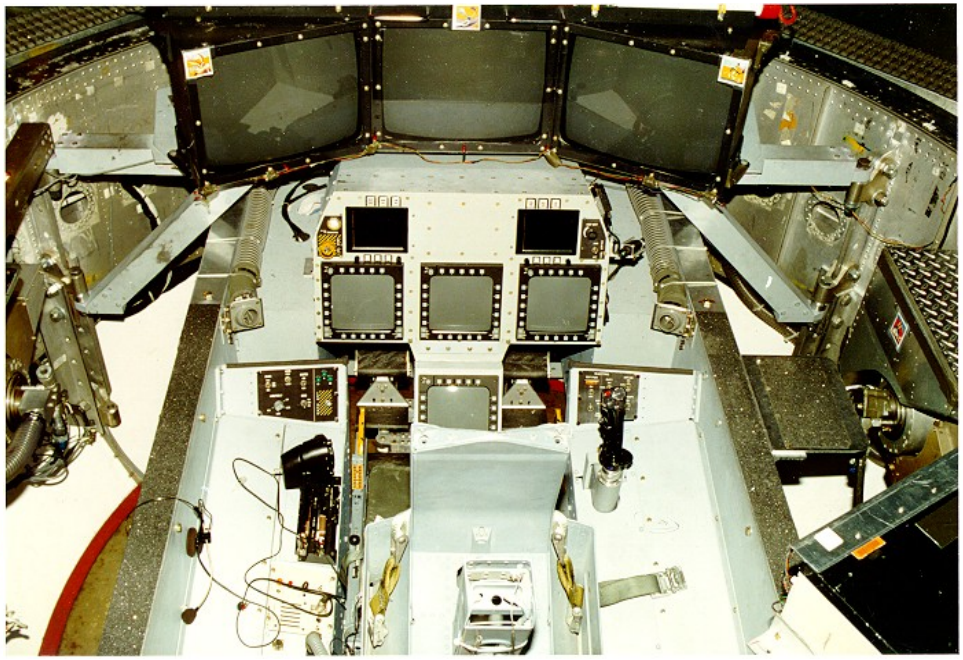
GOALS

1. Aircrew Survival
2. Aircraft Survival
3. Mission Effectiveness

Truth Table														SCC Action	Goals
1	2	3	4	5	6	7	8	9	10	11	12	13	RULE #		
0	0	0	0	0	--	0	0	0	0	0	0	0	0	Do Nothing	N/A
0					--			--				1	1	ASR active, GCAS inhibited, display spin info	1,2
--					--						1		2	PMWS active, display PMWS info	2,3
0					--			--			1	1	3	Do (1) and (2)	1,2,3
--					--					1			4	Lower G & V limits via SST, tell Sim, display alert to pilot, inform systems	2
0					--			--		1		1	5	Do (4) then (1)	1,2
--					--					1	1		6	Do (4) then (2)	2,3
0					--			--		1	1	1	7	Do (4) then (2) then (1)	1,2,3
--					--				1				8	SEA active, turn on lights/switches, inform pilot of ECS leak	2
0					--			--	1			1	9	Do (8) and (1)	1,2
--					--				1		1		10	Do (8) and (2)	2,3
0					--			--	1		1	1	11	Do (8), (2) and (1)	1,2,3
--					--				1	1			12	Do (8), (4)	2
0					--			--	1	1		1	13	Do (8), (4), (1)	1,2
--					--				1	1	1		14	Do (8), (4) (2)	2,3
0					--			--	1	1	1	1	15	Do (8), (4), (2), (1)	1,2,3
--					--			1					16	GCAS has control - display information	1,2
0					--			1			1		17	Do (16) and (2)	1,2,3
0					--			1		1			18	Do (4) and (16)	1,2
0					--			1		1	1		19	Do (6) and (16)	1,2,3
0					--			1	1				20	Do (16) and (8)	1,2
0					--			1	1		1		21	Do (16) and (10)	1,2,3
0					--			1	1	1			22	Do (4) then (8) then (16)	1,2
0					--			1	1	1	1		23	Do (16), (14)	1,2,3
--			--		--		1	--				--	24	Alert SES, display "plane uncontrollable", display time, alt. info, inhibit GCAS, inhib ASR	1,2
--					--	1							39	Notify pilot of threat postion via SAI	1,2
--	1	--	--	--	--	--	--	--	--	--	--	--	620	Tell pilot EJECT NOW! and activate SES, pilot selectable alt, time info available via SAI	1
1					--								621	Do Nothing	N/A
1	--	--	--	--	1	--	--	--	--	--	--	--	622	Can't Do	N/A
1					--			--				1	623	Do 1, Display SES info	1,2
1					--						1		624	Do 2, Display SES info	1,2,3
1					--			--			1	1	625	Do 3, Display SES info	1,2,3
1					--					1			626	Do 4, Display SES info	1,2
1					--			--		1		1	627	Do 5, Display SES info	1,2
1					--					1	1		628	Do 6, Display SES info	1,2,3
1					--			--		1	1	1	629	Do 7, Display SES info	1,2,3
1					--				1				630	Do 8, Display SES info	1,2
1					--			--	1			1	631	Do 9, Display SES info	1,2
1					--				1		1		632	Do 10, Display SES info	1,2,3
1					--			--	1		1	1	633	Do 11, Display SES info	1,2,3
1					--				1	1			634	Do 12, Display SES info	1,2
1					--			--	1	1		1	635	Do 13, Display SES info	1,2
1					--				1	1	1		636	Do 14, Display SES info	1,2,3
1					--			--	1	1	1	1	637	Do 15, Display SES info	1,2,3

SMART COCKPIT CONTROLLER EVALUATION IN NAVY'S UMAN CENTRIFUGE / DYNAMIC FLIGHT SIMULATOR COCKPIT





SMART COCKPIT CONTROLLER AGENT INTERFACE LESSONS LEARNED

- **FORMAL METHODS ARE IMPORTANT TO CAPTURE AGENT REQUIREMENTS.**
  - **REQUIRE WRITTEN INPUTS WITH ASSUMPTIONS AND GOAL ATTAINMENT VALUES.**
  - **ESTABLISH PROCESS TO GATHER INPUTS, DISTRIBUTE INFORMATION, GET TEAM FEEDBACK, AND FINALIZE REQUIREMENTS.**
- **PRODUCTION RULES FROM TRUTH TABLE SUCCESSFULLY DEMONSTRATED SCC DECISION / CONTROL PROCESS WITH**
  - **EXHAUSTIVE LARGE DATA SET**
  - **DISCRETE (BINARY) INPUTS**
- **BINARY TRUTH TABLE APPROACH TOO BRITTLE TO MANAGE PILOT-VEHICLE INTERFACE (PVI).**
  - **A COMBINATION OF NATURALISTIC DECISION MAKING & COGNITIVE MODELING APPROACH MAY BE MORE ROBUS**
  - **TIMEFRAME FOR TACTICAL DECISIONS (15 SEC - 5 MINUTE AGENT INTERFACE FUNCTIONALITY AND DESIGN.**

AIRCREW DECISION SUPPORT SYSTEM (ADSS) OVERVIEW

AIRCREW DECISION SUPPORT SYSTEM

TECHNICAL CAPABILITY

- ASSESS CURRENT SITUATION.
- ADVICE FOR SELECTING A COURSE O ACTION
- OPTIMIZE AIRCREW WORKLOAD THROUGH ADAPTIVE AUTOMATION
- PROTECT AIRCREW / AIRCRAFT FROM ENEMY THREATS AND TERRAIN CRASHES

OBJECTIVE:

- DEVELOP AND VALIDATE AN AIRCREW DECISION SUPPORT SYSTEM FOR NEXT GENERATION TACTICAL AIRCRAFT (F/A-18 E/F & JOINT STRIKE FIGHTER).

EXPECTED PAYOFFS

- REDUCED AIRCREW DECISION MAKING TIME 50% RESULTING IN 50% IMPROVEMENT IN A/G & A/A TARGET I
- REDUCED AIRCREW WORKLOAD AN FATIGUE 25% RESULTING IN ESTIMATE REDUCTION OF 8 AIRCREW DEATHS
- ESTIMATED $4 BILLION COST SAVIN YEAR DUE TO 75% IMPROVEMENT I AIRCREW / AIRCRAFT SURVIVABILI

ANGEL SOFTWARE MODULE (INTELLIGENT AGENT & DECISION

INTELLIGENT AGENT

DECISION OPTIONS

ADAPTIVE INFO. (FORMATS)

ADAPTIVE AUTOMATION

ADAPTIVE INTERFACE

VOICE QUERY

TASK FOCUS

ADVICE

PRIORITY MANAGER

DECISION TABLE

PROBLEM AREAS (39)

•	•	ALT. < MDA	AIRCREW TASK SATURATED	A/C UNRECOV.	ACTIONS
0	0	0	0	1	EJECT PROMPT
0	0	0	1	0	AUTOMATE SELECTED TASKS
0	0	1	1	0	• AGCAS • AUTO. SEL. TASKS
•	•	•	•	•	•

MISSION PERFORMANCE / PROBLEM PREVENTION

AIRCREW / AIRCRAFT SURVIVABILITY AND PROBLEM PREVENTION

OUTPUT ACTIONS

INPUT DATA

OUTPUT ACTIONS

SHARED MEMORY

OUTPUT ACTIONS

INPUT DATA

ENABLING TECHNOLOGIES

SMART ESCAPE SYSTEM

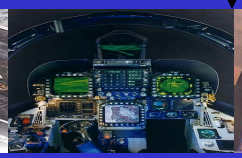
TAILSS

PVI:
- VOICE REC.
- 3D AUDIO
- HMD

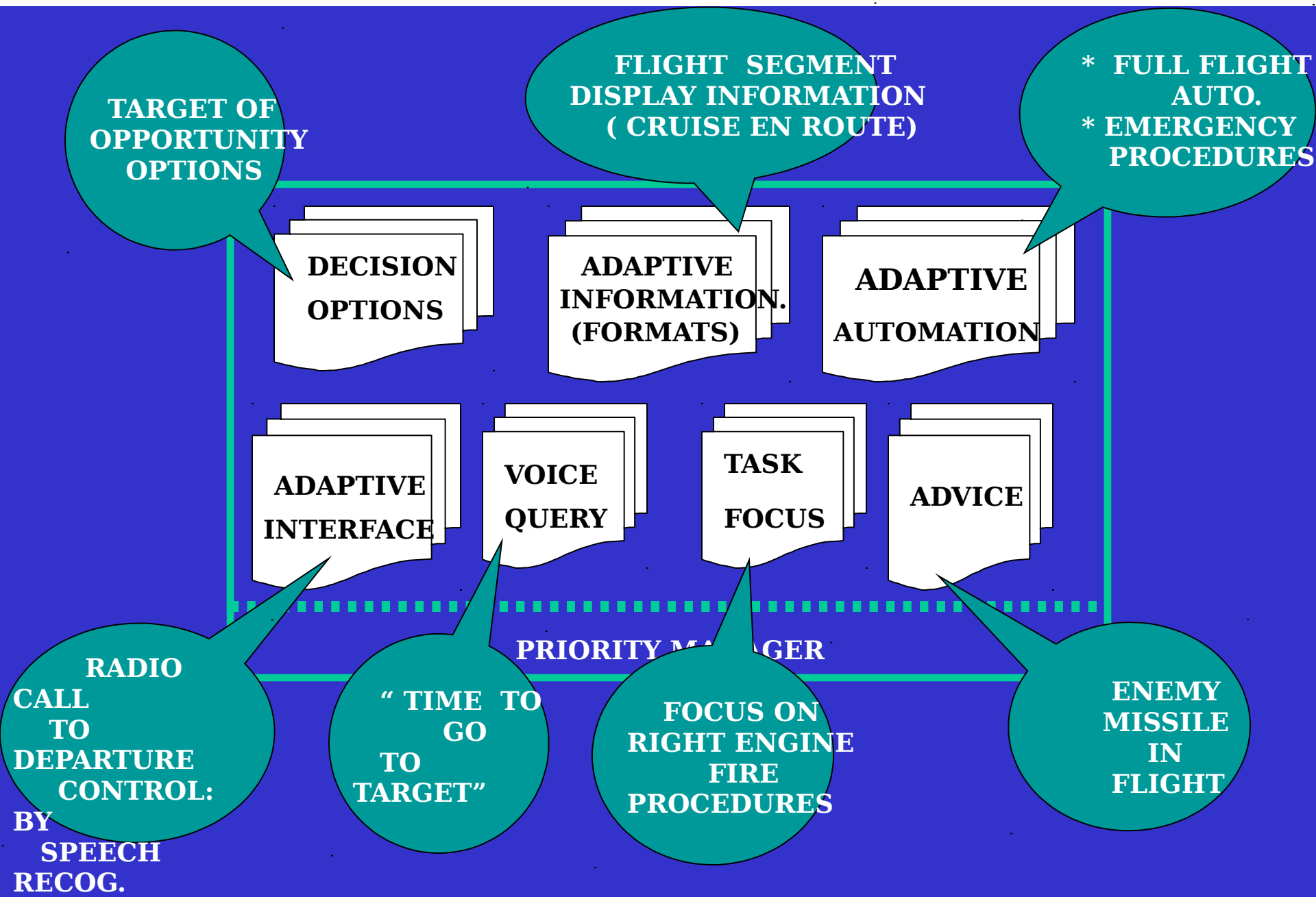
AUTO GROUND COLLISION AVOID. SYSTEM

MIDAIR COLLISION AVOID. SYSTEM

INTEG. CAUTION & WARNING SYSTEM



INTELLIGENT AGENT FUNCTIONALITY EXAMPL

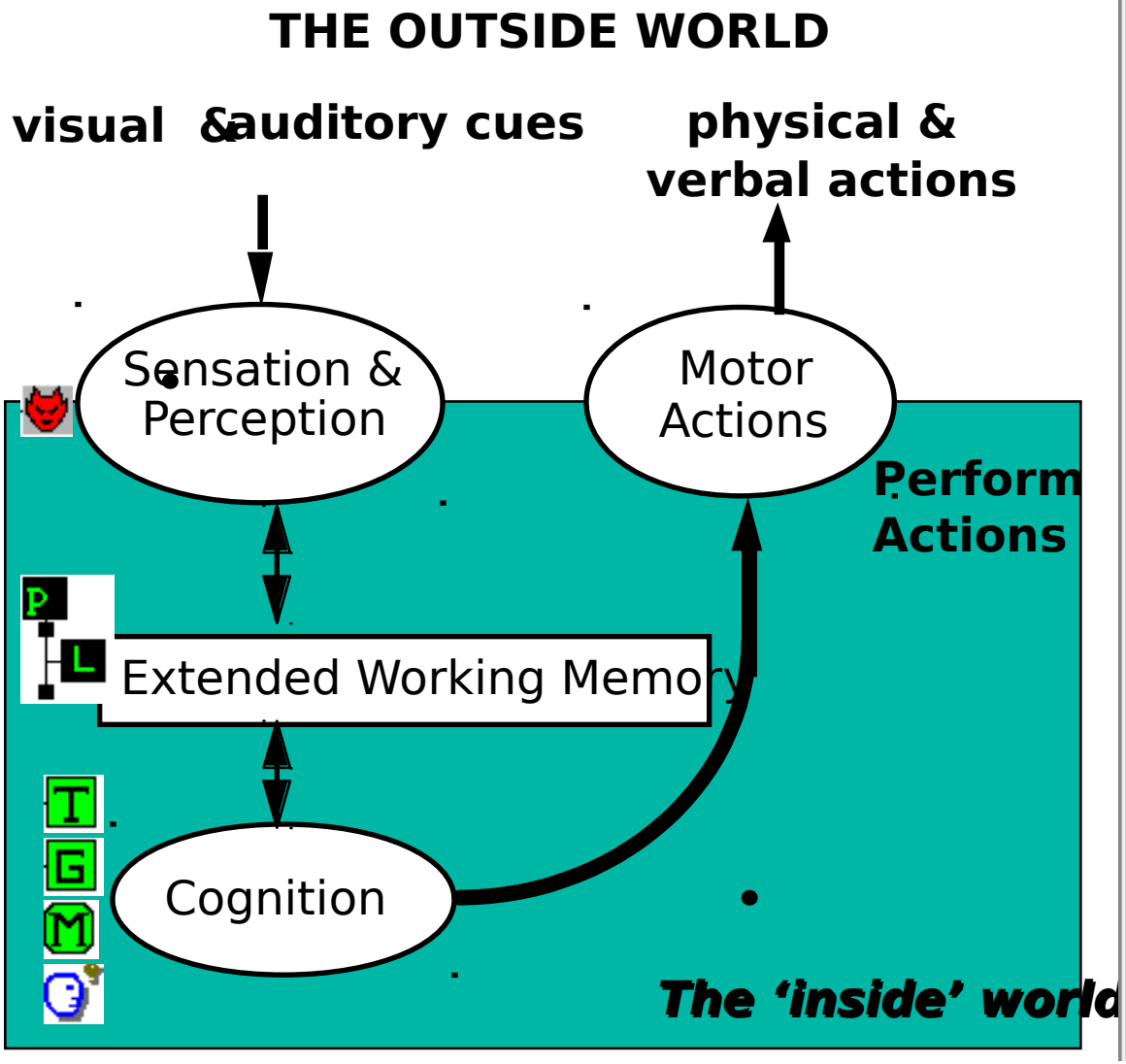


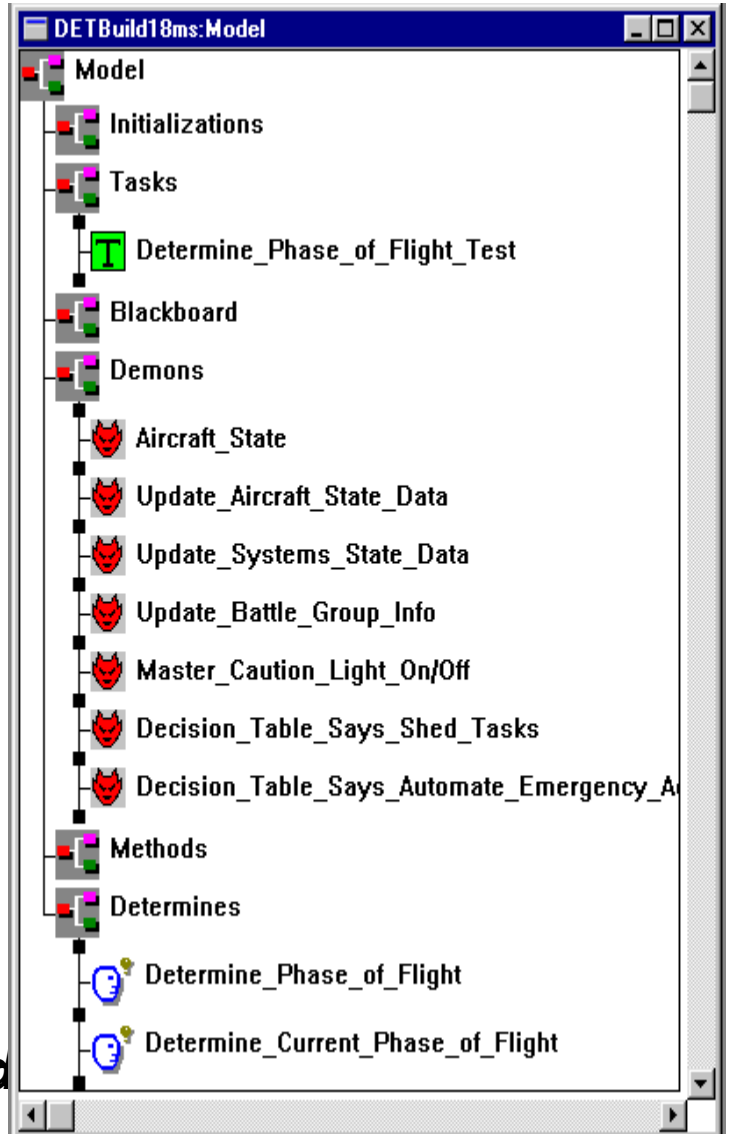
Intelligent Agent Based on a Knowledge Framework

(iGEN Cognitive Modeling Tools)

- **Expert oriented**
- **Declarative knowledge**
  - **multi-panel blackboard, with semantic links**
- **Procedural knowledge chunks (cognitive tasks)**
  - **compiled goal hierarchies**
  - **read and modify declarative blackboard**
- **Perceptual demons**
  - **self-activating encoding rules**
- **Action knowledge**
- **Meta-Knowledge**
  - **Knowledge-applicability contexts (task triggers)**
  - **Situational priority**

Expertise Components





Intelligent Agent Functional Layers

	Executive Layer	Control Layer	
Adaptive Automation	•High-Level •Oversight	•Low-Level •Performance	Decision Table
Decision Options	•Courses of Action •Recommendations	•Individual Actions •Automation	PVI
Adaptive Information	**EXAMPLES** Situation Assessment Context Evaluation	**EXAMPLES** Aircrew monitoring System monitoring	Cockpit Simulator
Adaptive Interface	Decision Making	Task performance	
Voice Query	Task Prioritization Task Monitoring Task Selection	Procedure prioritization Procedure performa Procedure monitoring	Enabling $Tech_1$
Task Focus		Application control Environmental feedback	• • •
Advice			Enabling $Tech_n$

How It Works: Executive Layer

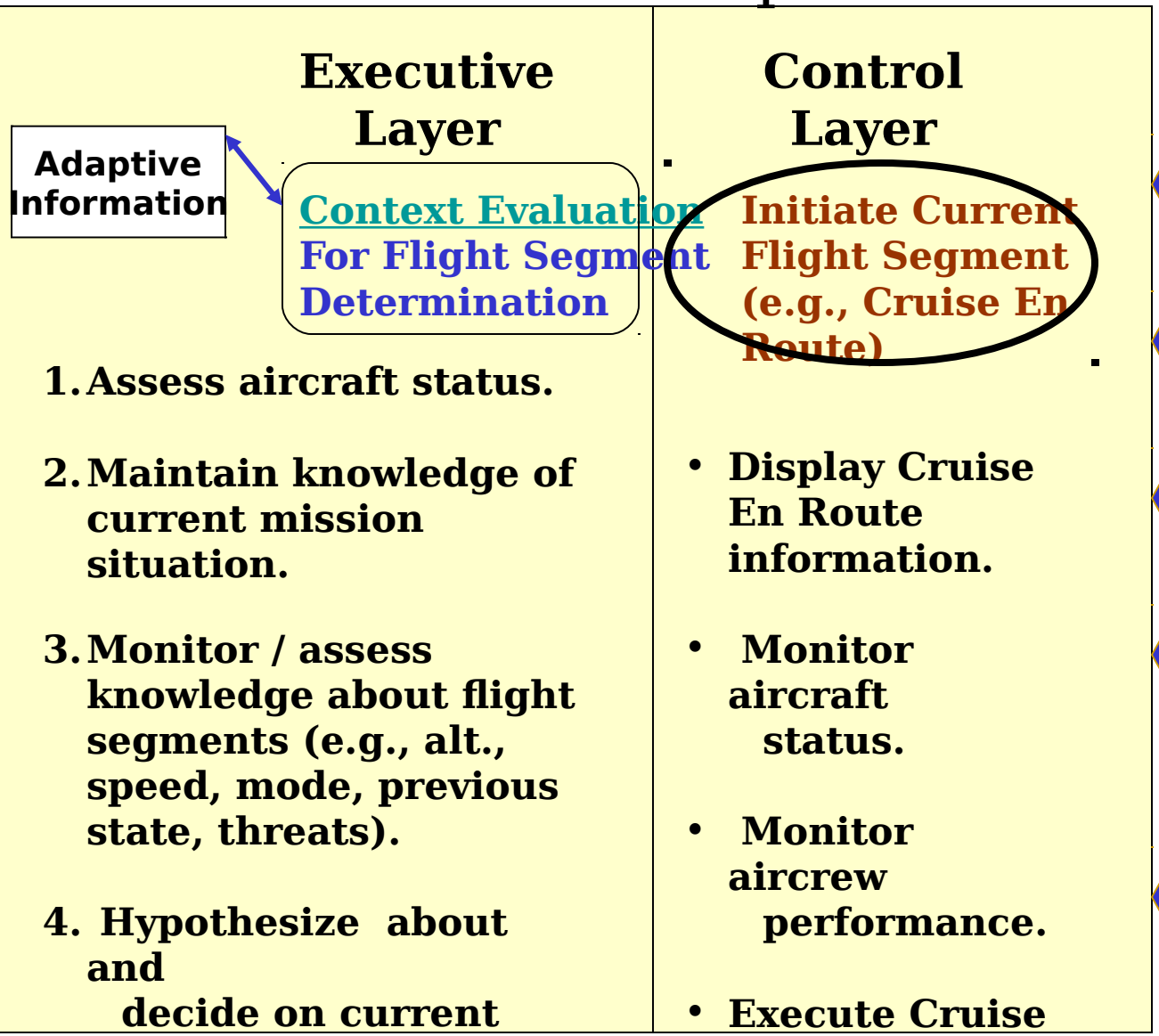
- **Monitor to Ensure A/C at Right Place at Right Time**
- **Monitor Flight Control (e.g., Attitude; or Aviate)**
- **Maintain Tactical Picture**
- **Monitor Each Phase of Flight**
- **Monitor Threat Detection and Defense**
- **Monitor Enabling Subsystem Actions**
- **Monitor Pilot Actions**
- **Monitor System Checks**
- **Handle Pilot Queries to PVI**
- **Provide ADSS Functionality on Command from Decision Table**

How It Works: Control Layer

- **Declarative Knowledge in Blackboard**
- **Procedural Knowledge in Methods**
- **Meta-Knowledge about Procedures in Blackboard**
- **Decisions in Goal Preconditions and Determines**
- **Demons Record Observed Aircrew Actions in Blackboard**
- **Expectations Posted in Blackboard by Tasks**
  - **Expected Procedures**
    - **Expected Action Sequences**
  - **Expected Threats from Mission Planning (Initialized at Start)**
  - **On-the-Fly Expectations from Real-Time Info**
    - **Threats Targets (New, Changed, Moved, Dropped, Destroyed,…)**
    - **Friendly Forces, Allied Forces, Opposing Forces, Others…**
- **Ensure Timely Actions (either by aircrew or agent)**
  - **Monitor, Remind and Assist (with PVI), or Automate**

Functional Layers

Example


Executive Layer
Control Layer
Adaptive Information
Context Evaluation For Flight Segment Determination
Initiate Current Flight Segment (e.g., Cruise En Route)
1. Assess aircraft status.
2. Maintain knowledge of current mission situation.
3. Monitor / assess knowledge about flight segments (e.g., alt., speed, mode, previous state, threats).
4. Hypothesize about and decide on current flight
• Display Cruise En Route information.
• Monitor aircraft status.
• Monitor aircrew performance.
• Execute Cruise En Route
Decision Table
PVI
Cockpit Simulator
Enabling Tech1
Enabling Techn

ADSS Future Tactical Cockpit

ADSS LESSONS LEARNED

1. Need computer tools, which support all knowledge engineering phases to reduce labor / time requirements.

   - tools would include the capability to perform:
   (a) agent domain definition
   (b) Knowledge elicitation (i.e., data capture and data management)
   (c) functional and detail requirement specification
   (d) interface design

   - tools need to support requirement definition through reliability & validation including auto coding.

2. Behavioral & cognitive task analyses are beneficial in establishing initial decision support system requirements. However, due to changing conditions (e.g., missions, tactics, weather), extensive usability testing and refinement is required for the decision support system to be robust.

ADSS LESSONS LEARNED

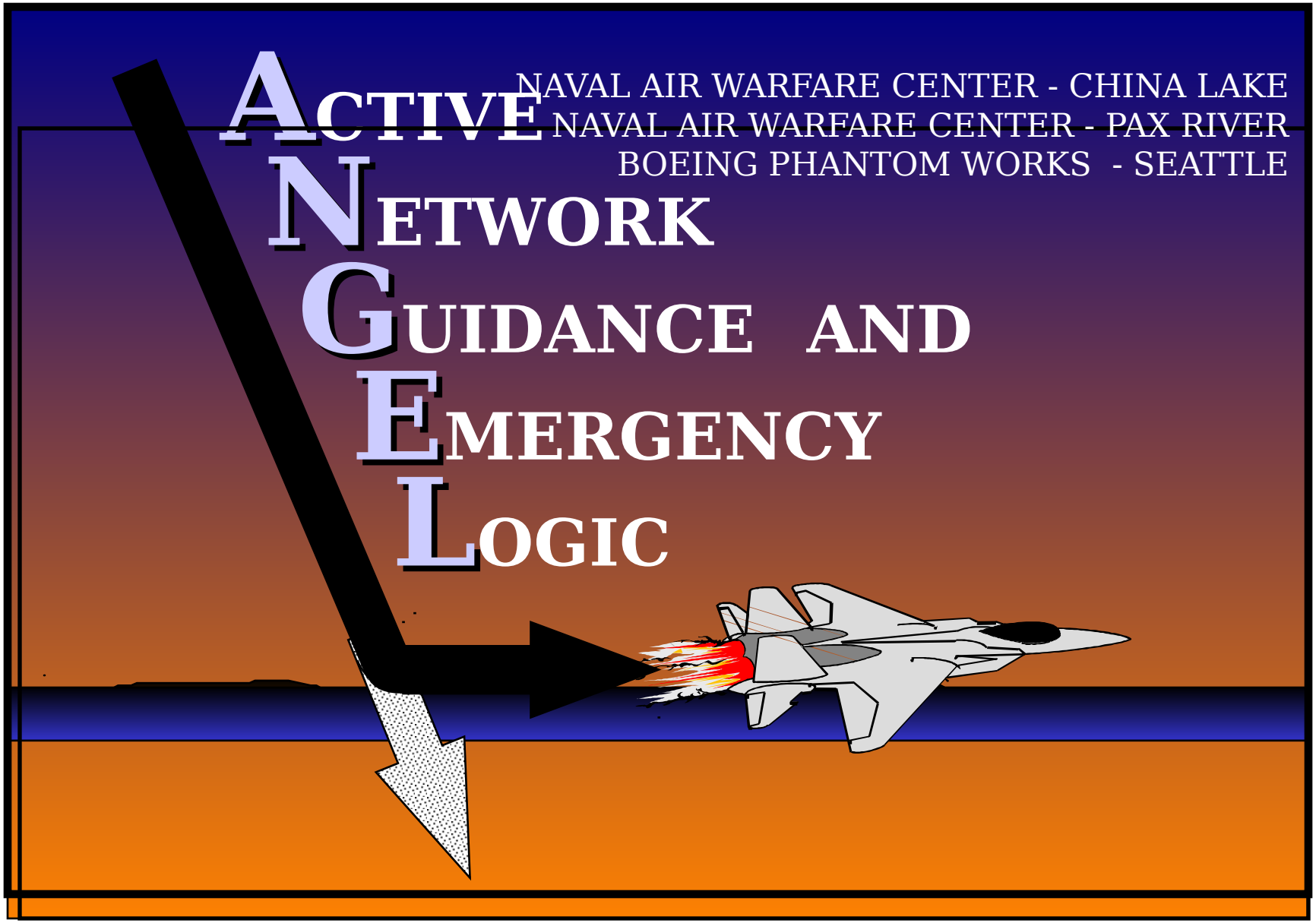
3. In representing and controlling the pilot-vehicle interface a combination of naturalistic decision making & cognitive modeling was more robust than a binary state approach.

4. Timeframe for decisions (e.g., 15 sec versus 5 minutes) drive agent interface functionality and design. Decision timeframe also determines types of decision support (e.g., naturalistic, adaptive automation, and full automation).

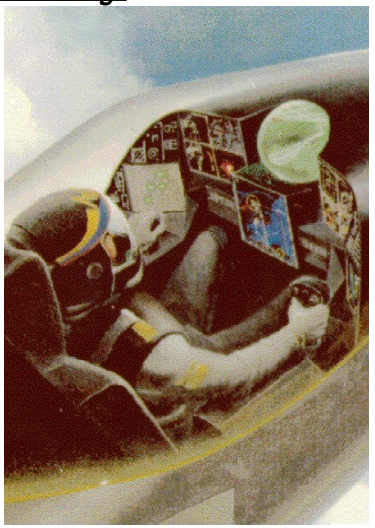
5. Need to develop a cognitive model taxonomy that identifies the advantages / disadvantages / domains of use / etc. of current cognitive models (e.g., ACT-PM, SOAR, iGEN) along with new models as they are developed. Taxonomy will aid in model selection

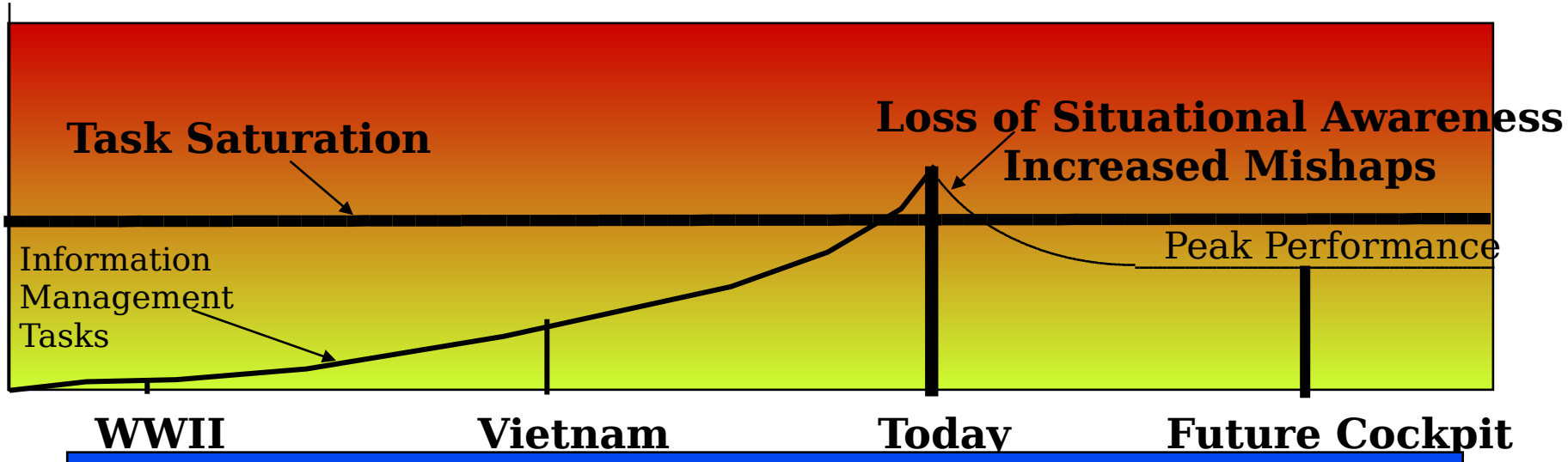
NAVAL AIR WARFARE CENTER - CHINA LAKE
NAVAL AIR WARFARE CENTER - PAX RIVER
BOEING PHANTOM WORKS - SEATTLE

ACTIVE NETWORK GUIDANCE AND EMERGENCY LOGIC



ANGEL GOALS - Maintain Optimum Mission Performance, Prevent Problems, Improve Aircrew and Aircraft Survivability





ANGEL provides pilot with 'virtual copilot' with three levels of support (goa

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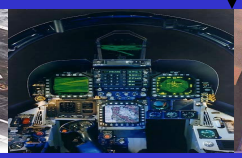

CURRENT ANGEL LESSONS LEARNED

- **REQUIREMENTS DEVELOPMENT FOR DECISION TABLE MATRIX WAS VERY LABOR AND TIME INTENSIVE.**

- **NEED COMPUTER TOOLS WHICH SUPPORT ALL KNOWLEDGE ENGINEERING PHASES TO REDUCE LABOR / TIME DEMANDS.**

- COMPUTER TOOLS CAN BE MOST BENEFICIAL IN ASSISTING IN DATA CAPTURE, AND DATA MANAGEMENT.

- TOOLS NEED TO SUPPORT REQUIREMENTS DEFINITION THROUGH RELIABILITY & VALIDATION INCLUDING AUTO - CODING.

- ANGEL PROGRAM PRODUCED A GENERAL SOFTWARE PROGRAM TO CHECK RELIABILITY & VALIDITY OF BINARY DECISION MATRIX (KAAT TOOL AVAILABLE ON CD-

DYNAMIC TASK ALLOCATION

•**RESEARCH OBJECTIVES**:

(1) To Develop a Skill-Based Paradigm Including Agent Learning for Human-Agent Dynamic Task Allocation.

(2) To Empirically Assess, Revise and Validate the Dynamic Task Allocation Skill-Based Paradigm.

•**LONG TERM GOALS**:

(1) Understand the Processes Involved in Performing Dynamic Task Allocation Between a Human and an Intelligent Agent.

(2) Understand How Agent Learning Can Be Applied in Human-Agent Dynamic Task Allocation.

•**PRODUCTS**: **(1)** a Skill-Based Paradigm for Human-Agent Dynamic Task Allocation, **(2**) Empirical Evaluation and Validation of the Paradigm and **(3)** Principles and Guidelines for Human-Agent Dynamic Task Allocation.

Technical Approach

COMPONENTS OF SKILL-BASED PARADIGM

Multiple Flight Test Skill Battery (MFTS)

Skills *

- **Psychomotor**
- **Auditory**
  - Sound/Localization
  - Auditory Attention
- **Visual Discrimination**
- **Cognitive**
  - Reasoning

    Information ordering, inductive reasoning, deductive reasoning, numerical reasoning
  - Conceptual

    Visualization

    Spatial Orientation
  - Memorization
- **Speed Loaded**
  - Perceptual Speed
  - Time Sharing

Individual and Group Skill Profiles

- Most Proficient Skills
- Least Proficient Skills

Agent Functionality

- **What** to automate/areas for decision aiding.
- **How** to automate and provide decision aiding.
- **When** to provide automation/decision aiding.

Agent Learning Techniques

Addresses:

- Dynamic human-agent task prioritization.
- Human-agent feedback.
- Task control back to human

Note: Skill types were selected from Fleishman, E.A. & Quaintance, M.K. (1984) Taxomonies of Human Performance: The Description of Human Tasks. Orlando: Academic Press.

AREAS FOR FUTURE RESEARCH

1. **NEED COMPUTER TOOLS**, WHICH SUPPORT ALL KNOWL ENGINEERING PHASES TO REDUCE LABOR / TIME REQUIREMENTS.

   - TOOLS INCLUDE: (A) AGENT DOMAIN DEFINITION
     (B) KNOWLEDGE ELICITATION
     (C) FUNCTIONAL & DETAIL REQ. S
     (D) INTERFACE DESIGN
     (E) RELIABILITY & VALIDATION

2. **NEED TO DEVELOP A COGNITIVE MODEL TAXONOMY** TH IDENTIFIES THE ADVANTAGES / DISADVANTAGES / DOM USE / ETC. OF CURRENT COGNITIVE MODELS (E.G., ACT- SOAR, IGEN) ALONG WITH NEW MODELS.

   - TAXONOMY WOULD AID IN MODEL SELECTION DU DECISION SUPPORT SYSTEM DEVELOPMENT.